Relevant Computing Curricula in Sub-Saharan Africa

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Abstract. The principle objective of this research was to establish what computing curricula are required for the Sub-Saharan Africa region. Input from academics, businessmen and the analyses of curricula from several African universities revealed a gap between existing curricula and what is considered to be ideal for this region. Required knowledge clusters were identified: Science and Technology; Soft and Research skills; Society and Development; Environment; Business and Entrepreneurship; Institutional; and Practical Skills. These were used to propose a model for enhancing the computing curricula of the Association of Computing Machinery and the Institute of Electrical and Electronic Engineers' for the SSA region.

Keywords: computing curricula, curriculum development, relevant curricula

1 Introduction

Computing as a discipline was adopted by some Sub-Saharan African (SSA) universities only in the early 1990s, many years after computing was an established discipline in the United States of America (USA)–in 1993 Odedra et al. noted: "*Only a handful of countries such as Nigeria, Malawi and Zimbabwe have universities that offer computer science degrees*." [1]. In the USA such programmes emerged in the 1960s [2]. The first (and still the most popular) of the computing disciplines to be adopted in SSA was computer science (CS), which was in most cases initially hosted in the mathematics units of the institutions, with mathematicians delivering most of the modules of these CS programmes. As capacity building for CS trainers became necessary, graduates of mathematics trained at MSc or PhD level in disciplines related to CS. Obviously, those who did not train in CS at the undergraduate level lacked aspects of CS foundation and thus could not competently undertake the research required by higher degrees in CS.

At the time most institutions offered CS as a major with mathematics-related disciplines such as mathematics or statistics as a second major. As CS gained popularity and more CS training capacity became available, institutions established stand-alone departments to host the CS programmes.

Computing disciplines, defined jointly by the ACM (Association for Computing Machinery) and IEEE (Institute of Electrical and Electronic Engineers) Computer Society are: computer science (CS); information technology (IT); information systems (IS); software engineering (SE); and computer engineering (CE) [2]. In addition to defining core knowledge areas for each discipline, the joint committee of the ACM and IEEE define clear boundaries amongst the different but otherwise overlapping computing disciplines (see **Fig. 1**). In addition, they provide detailed recommendations of specific modules and the relative importance of each discipline.

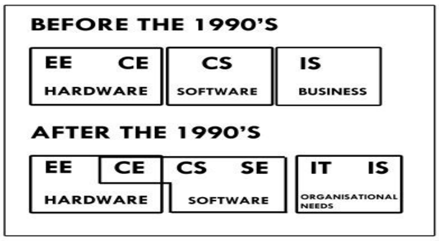

Fig. 1. Focus of the various computing disciplines [2]

Curricula cannot be developed in isolation but must consider *community* challenges so that graduates have the necessary skills to address these community challenges. The needs of a community can be very distinct depending on how the community is defined. At a micro-level, communities can be seen as local groups of people geographically located in a close proximity. The people who share a common culture, and often language, are subject to some form of socio-economic environment that can be uniquely identified and differs from what communities in other geographic areas experience. Consequently curricula recommendations developed by experts from one community may fail to consider the needs of other communities. SSA has unique challenges and needs, and thus relevant knowledge areas (curricula knowledge clusters) need to be considered for SSA institutions.

As citizens of the so-called global village, SSA graduates should have skills that will enable them to work for any global IT company. Additionally they should be equipped with more specific skills to tackle challenges faced by their communities. Related to the need for the development of the region, graduates from SSA (much more than their counterparts in the developed world) should be able to build their own IT businesses—small and medium enterprises (SMEs) have proven to contribute significantly to economic growth in the SSA region [3].

In August 2010, a two-day summit was organised and held in Kampala, Uganda, and computing scholars, from all parts of SSA–West Africa, South Africa and East Africa–attended. The aim of the summit was to determine what graduate attributes are required of SSA graduates other than what is considered to be the "problem space" as defined by the ACM & IEEE (see **Fig. 2**). Stakeholders from some local IT industries were invited to contribute on what skills (from their experience) they would appreciate in SSA graduates. At the summit, a task force was constituted (and given terms of reference) to design a tool for the quantitative and, to a lesser degree, qualitative, analysis of data collected from various institutions in SSA.

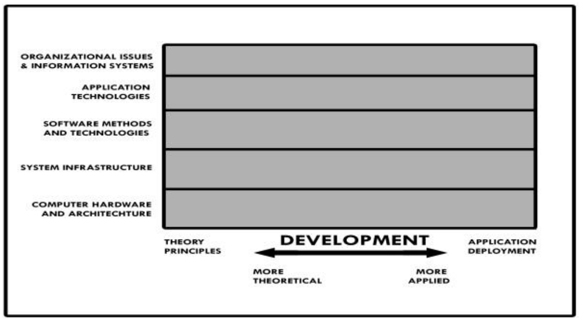

Fig. 2. Problem space of computing as defined by the ACM & IEEE [2]

The remainder of the paper is organized as follows: the outcomes of the summit are presented in Section 2; the collected data and the findings derived from the analysis are presented in Section 3; recommendations are outlined in Section 4; and, finally, conclusions are drawn in Section 5.

2 The outcomes of Kampala summit

The two-day summit was attended by 40 educators in computing disciplines from around the continent (15 universities from Sub-Saharan Africa were present), some IT practitioners and some researchers from in- and outside Africa.

Before the summit, all participants completed an online pre-summit questionnaire to gather ideas, which fed into the summit agenda. On the first day of the summit, participants discussed various matters pertaining to their existing programmes (design issues, accreditation, pedagogy, delivery methods, relevance, managing stakeholders' expectations, and supporting resources such as infrastructure, laboratories and software). The first session ended with a plenary session, lead by a panel of four chief executive officers (CEOs) of local IT industries. These industrialists are IT entrepreneurs in Uganda who own and leed IT businesses largely focusing on software development. Their companies employ on average 20 staff each. In addition, they have been interacting with students doing internships or fieldwork. The objective of including IT businessmen in the summit was to get feedback from them on what they felt are the gaps in the skills-base of the graduates they employ.

The following is a summary of the aspects highlighted by the industrialists (detailed feedback can be obtained from the summit website [4]). The industrialists felt that there was:

- A *lack of basic skills and the ability to work independently;*
- *Limited problem solving skills;*
- *Inability to handle practical problems; and*
- *Poor communication skill.*

Furthermore the industrialists observed that:

- *Top students are just naturally smart irrespective of what they were taught;*
- *Content should be real-world based and relevant to the local the industry;*
- *Technology changes very fast – students should acquire the basic skills to allow them to become life-long learners; and*
- *Communication and problem solving skills should be integrated within other modules.*

This feedback shed some light on what skills-base is required, and what needs to be considered when developing a relevant computing curriculum for SSA.

Table 1. Knowledge clusters and corresponding topics

Science and Technology: Theory, Design, Modeling
Soft and Research Skills: Problem solving, Team work, Communication
Society and Development: Community outreach, Ethics, Learner centric teaching
Environment: E-waste, Carbon footprint, Health
Business: Innovation, Commercialisation, Entrepreneurship
Institutional: Management and organisation, Structure, Governance
Practical Skills: Projects, Field work, Internship

During discussions on the second day of the summit, the delegates identified the *knowledge clusters* (building blocks of skills or knowledge areas) they felt should be part of each curriculum. The meeting came up with 7 knowledge clusters, namely: Science and Technology (S&T); Soft and Research skills (S&R); Society and Development (S&D); Environment (ENV); Business and Entrepreneurship (BU); Institutional (INST); and Practical Skills (PR). Each of these knowledge clusters can further be defined by a number of knowledge areas. The detailed definition and examples for each knowledge cluster is shown in **Table 1**.

Table 2. The current state of programmes

	S&T	**S&R**	**INST**	**S&D**	**ENV**	**BU**	**PR**
CS	4	1	1	1	0	1	4
SE	4	1	1	0	0	1	4
IS	3	1.5	3	1	0	2	4
IT	2	1	3	1	0	2	4
CE	4	1	0	1	1	1	3

Table 2 shows the degree of importance (0 = least- and 5= most-important) of each knowledge cluster in current computing programmes as agreed upon by the delegates during the summit. From the table it can be seen that some of the knowledge clusters (ENV, S&D, S&R and INST) are considered to be very low or non-existent for most

of the current computing disciplines. Even for S&T the delegates indicated that the degree of importance was less than optimal.

Table 3. The degree of importance for the ideal computing programme

	S&T	S&R	INST	S&D	ENV	BU	PR
CS	5	4	2	3	2	2	5
SE	5	4	3	3	1	3	5
IS	3	5	5	4	2	4	5
IT	2	5	4	4	3	3	5
CE	5	4	1	3	4	3	5

Table 3, on the other hand, shows the degree of importance delegates believes each of the knowledge clusters should have, in order to constitute the ideal relevant computing curricula for SSA. There is a distinct discrepancy between **Table 3** and **Table 2**. In effect, the summit delegates believed more emphasis should be placed on both the PR (Practical) and the S&T (Science and Technology) knowledge clusters. They felt that S&T should be more emphasized for CS, SE and CE compared to IT and IS. IT and IS, it was felt, should emphasize S&R (soft and research skills), INST (institutional skills), and S&D (society and development). It is clear that some knowledge clusters such as S&R, S&D, ENV and BU currently receive little emphasis. Albeit to a lesser degree, this also applies to the S&T knowledge cluster, which is considered to be a core element of most computing programmes. The outcomes of the Kampala summit are based on the rich integrated experiences of computing academics in SSA and a selected number of experts from industry. It indicates that the largest gaps are in soft and research skills as well as the skills to explore societal developmental needs.

At the end of the summit, a task force was established to develop tools to empirically investigate the existing computing programmes in SSA in order to establish the gap based on realistic data from the programmes. In the next section, the developed tools for the quantitative analysis (excluding the qualitative analysis) of the programmes are presented as well as the findings derived from the data.

3 Data Analysis and Findings

A task force of six academics–two each from East, West and South Africa–was constituted to collect data about the syllabi of the computing programmes currently being taught in their respective regions. The findings of the team were an important step towards validating the gaps between the existing curricula and the identified knowledge clusters. Syllabi from a total of 22 computing programmes were collected and analysed. More than half of the syllabi (13 of the 22) were CS, three were IT, three were CE, two were IS, and only one was SE. It is not surprising that the most popular of the computing programmes in SSA is still CS (the oldest discipline among the computing disciplines). The rest of the programmes are new to SSA. Of the universities considered, most offer CS only, a few offer two computing disciplines and one offers all computing disciplines as defined by the joint IEEE and ACM committee.

Table 4. Analysis of 15 CS programmes in terms of the defined knowledge clusters

CS	S&T	S&R	S&D	ENV	BU	INST	PR	E-PR	Years
CS_1	0.73	0.06	0.06	0	0.04	0.06	0.08	N/A	4
CS_2	0.77	0.025	0.075	0	0	0	0.08	N/A	3
CS_3	0.75	0.16	0	0	0	0	0.09	N/A	4
CS_4	0.82	0.06	0	0	0.036	0	0.14	0.112	3
CS_5	0.85	0.045	0.03	0	0.03	0	0.045	N/A	4
CS_6	0.88	0.064	0.056	0	0	0	0	N/A	3
CS_7	0.95	0.041	0	0	0	0	0	N/A	3
CS_8	1	0	0	0	0	0	0	0.2	3
CS_9	0.82	0.02	0.006	0	0	0	0.09	0.1	3
CS_{10}	0.79	0.045	0.054	0.02	0.02	0	0.073	N/A	3
CS_{13}	0.83	0.055	0	0	0.055	0	0.06	N/A	4
CS_{14}	0.86	0.03	0.03	0	0	0	0.07		3
CS_{15}	0.8	0.02	0.006	0	0.026	0.013	0.14	0.16	4
Max	1	0.16	0.075	0.02	0.055	0.06	0.14		
mean	0.83	0.048	0.024	0.001	0.015	0.005	0.066		
Min	0.73	0	0	0	0	0	0		

It was a challenge to collect the required data: only a few of the computing departments' syllabi are available online and many that were approached through other means did not respond; the representation of the data and the amount of information available differed considerably from one programme to another; and some universities offer programmes not defined by the joint IEEE and ACM committee.

Each module (for each programme) was categorised in terms of the knowledge clusters and whether it is core or an elective. The relative weight for each module (for each knowledge cluster) was computed as a fraction of the total CUs or CHs in the programme. For a few programmes, it was possible to identify the number of practical hours embedded within the knowledge clusters (it is shown as E-PR). **Table 4** shows the relative weight of each of the knowledge clusters for the 15 CS programmes collected from selected regions of SSA. It can be observed that in the existing programmes, significant emphasis is placed on the core technical module of all the programmes (S&T) and far less emphasis is placed on the remaining knowledge clusters. S&R (emphasized by the IT professionals) is only considered to be of relative importance and in only one programme constitutes more than 10% of the programme (CS_3).

The most popular S&R course is *Communication Skills*. It was not possible to establish if more skills were embedded within other knowledge clusters. The ENV and INST knowledge clusters are the least emphasized. Only one programme offered a module on ENV and two programmes offered INST modules. Only six programmes provided some modules on BU. Most programmes emphasised PR (Practical skills) either as a separate module or embedded within S&T modules. Where it was possible to determine its "embeddedness", it is provided in the E-PR column in Table 4. Relative weights provided in the table are based on individual modules that focus specifically on offering practical skills; it may include a final year project, field work/internship, or individual projects. In **Table 5** the data for other computing disciplines is shown. It can quickly be observed that a similar pattern in terms of emphasis given to the different knowledge clusters (as observed for the CS programmes) exists for the other computing programmes (IT, SE, CE and IS).

Table 5. Analysis of IT, SE, CE and IS computing programmes in terms of the defined knowledge clusters

IT	**S&T**	**S&R**	**S&D**	**ENV**	**BU**	**INST**	**PR**	**E-PR**
IT_1	0.71	0.114	0	0	0.03	0	0.15	
IT_2	0.56	0.036	0.115	0	0.115	0.06	0.06	0.12
IT_3	0.66	0.016	0.04	0	0.065	0.1	0.12	
Average	**0.635**	**0.075**	**0.057**	**0**	**0.073**	**0.03**	**0.105**	
SE								
SE_1	0.76	0.02	0	0	0.04	0	0.11	0.18
CE								
CE_1	0.82	0.1	0	0	0.02	0	0.1	N/A
CE_2	0.82	0.02	0	0.01	0.03	0	0.11	N/A
CE_3	0.82	0.02	0.007	0	0.03	0.0013	0.013	0.22
Average	0.82	0.047	0.002	0.003	0.027	0.0004	0.0743	
IS								
IS_1	0.64	0.11	0.03	0	0.086	0	0.133	
IS_2	0.7	0	0	0	0.27	0	0.023	N/A
Average	**0.67**	**0.055**	**0.015**	**0**	**0.178**	**0**	**0.078**	

Finally the syllabi of the participating CS computing programmes in SSA were analysed in terms of modules offered in each knowledge cluster. **Table 6** shows the number of modules (in each knowledge cluster) for the various CS programmes analysed and should thus not be used to compare the different programmes, since the number of credit units assigned for each module may differ greatly from one programme to another. What can be derived from the table is that there is very little emphasis on all the knowledge clusters, except S&T and PR, which is considered necessary for curricula in SSA. In the next section, recommendations regarding the development of computing curricula in SSA are presented.

Table 6. Number of modules per knowledge clusters for CS programmes

CS	S&T	S&R	S&D	ENV	BU	INST	PR	YRS
CS_1	36	1	3	0	2	3	4	4
CS_2	57	3	2	0	2	0	3	4
CS_3	46	8	0	0	0	0	2	4
CS_4	42	3	0	0	3	0	4	4
CS_5	49	1	1	0	2	1	6	4
CS_6	28	2	0	0	1	0	4	3
CS_7	34	3	2	0	0	0	0	3
CS_8	36	1	3	0	0	0	3	3
CS_9	34	2	3	1	1	0	4	3
CS_{10}	30	3	3	0	0	0	4	3
CS_{11}	36	2	2	0	0	0	3	3

4 Recommendations and conclusion

Before presenting recommendations, a few assumptions are made about the desired relevant computing curricula and the degree of importance of each of the knowledge clusters (see **Table 1**). These assumptions are:

- Each module in the programme contains the same number of credit units (CU) (that is 1.5% of the total number of CU in the programme):
- Each skill is provided using a separate module, i.e., skills are not embedded in any module.
- In total, the programme will have 100/1.5=67 modules distributed amongst the seven knowledge clusters in the defined programme.
- The goal is to derive some relative weights for each of the knowledge clusters for all computing programmes.

It is hoped that the process (adopted in this section) can serve as a benchmark for academics to follow when deriving their programmes. In order to get the relative weights for each knowledge cluster (based on the values provided in **Table 3**), and to determine the fraction of contact hours each knowledge cluster should have in each computing programme, the values in **Table 7** were intuitively defined by the authors. Relevant academic units can come up with a different distribution to yield the learning outcomes of the designed curricula.

Take CS for example, the values in the row show that 51% (equivalent to 51/1.5 = 34 modules) of the weight of the programme should be assigned to S&T, S&R covers 18% of the programme (12 modules), S&D, ENV and BU are covered by 2, 2, and 3 modules respectively, and finally the practical knowledge clusters is covered by 12 modules. To get the normalized weights for each knowledge cluster in each programme under the relevance metrics values obtained in **Table 3**, the corresponding values of knowledge clusters in **Table 3** and **Table 7** are multiplied for all entries in the tables and finally the resulting values is divided by the sum of values for all knowledge clusters of a given programme (see equation 1).

Table 7. Hypothetical relative weights

	S&T	S&R	S&D	ENV	BU	INST	Pr	Total
CS	0.51	0.18	0.03	0.03	0.04	0.03	0.18	1
IT	0.45	0.24	0.03	0.03	0.04	0.06	0.15	1
IS	0.45	0.24	0.03	0.03	0.04	0.06	0.15	1
SE	0.51	0.15	0.03	0.03	0.04	0.03	0.21	1
CE	0.51	0.15	0.03	0.03	0.04	0.03	0.21	1

Let W(i,j) be the weight assigned for a given knowledge clusters *j* of programme *i* in **Table 7**, and D(i,j) be the degree of importance of the same knowledge clusters of the programme in **Table 3**. The corresponding normalized relative weight of each knowledge cluster *j* of programme *i* is computed as

$$\boldsymbol{RW(i,j)} = \frac{\boldsymbol{W(i,j)D(i,j)}}{\sum_{\forall j} \boldsymbol{W(i,j)D(i,j)}} \qquad (\mathbf{1})$$

The normalized relative weights are shown in **Table 8**. The table offers some benchmark against which the values derived from the collected data presented in **Table 4** can be compared. What needs to be noted is that in **Table 8** no skill is embedded within the S&T modules. It nevertheless provides a good comparison for the remaining knowledge clusters. When comparing these two tables (**Table 4** and **Table 8**), it represents the outcomes of the discussions during the summit, and the findings of the collected data of computing syllabi in SSA.

Table 8. Proposed normalized relative weights for relevant computing curricula

	S&T	S&R	S&D	ENV	BU	INST	Pr
CS	0.57	0.16	0.02	0.013	0.020	0.013	0.20
IT	0.26	0.35	0.035	0.026	0.039	0.070	0.22
IS	0.34	0.30	0.030	0.015	0.045	0.076	0.19
SE	0.56	0.13	0.02	0.007	0.030	0.02	0.23
CE	0.56	0.13	0.02	0.026	0.030	0.007	0.23

Based on the initial findings of the workshop and the subsequent survey of institutions, a number of recommendations can be made for the development of future computing programmes in SSA:

- Firstly, and most importantly, curricula need to place greater emphasis on complementary skills to S&T as outlined in **Table 1**. The degree of importance of each of these areas to the different disciplines was outlined in **Table 3**. While this does not translate to numerical proportions of contact hours or credits, it does clearly indicate the relative importance of each knowledge cluster across disciplines. For example, S&T is the most important cluster for CS but S&R is the most important cluster for IT.

- Secondly, it is imperative that curricula are in fact assessed and improved on as soon as possible, given the clear distinction between the current and ideal distribution of effort across knowledge clusters in all the disciplines (as shown in **Tables 2** and **3**). The difficulty in obtaining information on curricula is a further concern that must be addressed by a greater sense of transparency at institutions. Current programmes are delivered differently in every institution and no effort is made to map one programme to another - thus finding and addressing gaps to improve on curricula requires substantial effort. A suitable auditable baseline should be adopted by all institutions as they move forward with curriculum development. This could be derived from ACM/IEEE/British Computer Society, augmented with topics in the non-S&T knowledge clusters identified in this study.

As these processes unfold, the lack of active community engagement in ACM and IEEE curricula must be addressed by appropriate involvement in the respective organisations. This will ensure that the results from this study are ultimately incorporated into future international curricula recommendations.

This outcome dovetails well with a recent study by academics from the Pacific Rim that concluded that CS curricula should be expanded, thus adapted, to suit their needs, which is to include international competitiveness, legal-, social-, and environmental-skills in their curricula: "... *internationalization will move our discipline towards the maturity and recognition it deserves, as more computer scientists move into leadership positions in commerce, education, and government"* [5].

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